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The Effect of Single Edge Notch Bend (SENB) Specimen Geometry to Fracture Properties of Aluminium Alloys Using Simulation Analysis

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Abstract: Aluminium alloys are strong yet light metals that are found uses in almost every market. An alloy is the mixture of metals which will be more useful when mixed than their constituent metals alone. Aluminium alloys are widely used as structural materials in aeronautical industries due to their attractive comprehensive properties such as low density, high strength, ductility, toughness and resistance to fatigue. Single Edge Notch Bend (SENB) specimen is an American Society for Testing and Materials E1820 standard fracture toughness testing specimen geometry. SENB specimen is a rectangular beam with a single edge notch under three point bend load. In this study is about the effect of single edge notch bend (SENB) specimen geometry to fracture properties of Aluminium alloys using simulation analysis. The finite element analysis, ANSYS software has been used to simulate the three point bending and four point bending test. The mechanical properties of the Aluminium alloys from the simulation analysis is studied and compared to the result from the previous research. The findings show that narrow notch specimen has the highest equivalent stress which is 1316.1 MPa, 1974.2 MPa and 2632.3 MPa for the respective load and the equivalent strain is 0.018649, 0.027974 and 0.037298 for the three point bending simulation test. For four point bending, four point bend specimen shows the highest equivalent stress at 869.29 MPa, 1303.9 MPa and 1738.6 MPa for the respective load. Equivalent strain is 0.0095638, 0.014 346 and 0.019128 for the AL6061-T6 material. This shows that the equivalent stress is increase when the load is increase. The material AL6061-T6 has the highest stress because of the chemical composition in the material. All material shows the plastic behavior on the specimen and at notch tip. This is because the higher the amount of plastic strain and the bigger plastic zone indicate the higher resistance towards notch opening on the specimen when the load increase.

Keywords: Single Edge Notch Bend (SENB), Plastic Deformation, Finite Element Analysis, ANSYS, Three Point Bending, Four Point Bending.

1. Introduction

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Aluminum alloys are strong yet light metals that are found uses in almost every market. An alloy is a mixture of metals which will be more useful when mixed than their constituent metals alone. Base metals can be improved by mixing with other small quantities of different metals that are known as alloying elements. Aluminium alloys are widely in used as a structural materials in aeronautical industries due to their attractive comprehensive properties such as low density, high strength, ductility, toughness and resistance to fatigue [1].

Finite element analysis is a computer-based handled utilized for modelling complex items and framework. This simulation happens in a virtual environment to solve or find a series of solutions to possibly complex the performance issues [2]. Single Edge Notch Beam (SENB) specimen is an America Society for Testing and Materials E1820 standard fracture toughness testing specimen geometry [3].

Some studies stated that different thickness of the SENB specimen can affect the fracture toughness of the specimens by using finite element analysis and experiment. The magnitude of the stress intensity factor depends on thickness and significantly varies along the crack-front of the specimen [4]. Another research indicate that the lesser the thickness used the lesser the chances of the specimen to undergo fatigue failure [5]. On the other hand, the effect of specimen geometry on fracture behavior of Aluminium alloys are rarely investigated.

The objective of this research is to determine the mechanical properties of Aluminium alloys using simulation for the SENB specimen. Another objective is to compare between the data of mechanical properties of Aluminum alloys that has been analyzed using FEM method and the data from the actual test method.

2. Materials and Methods

2.1 Materials

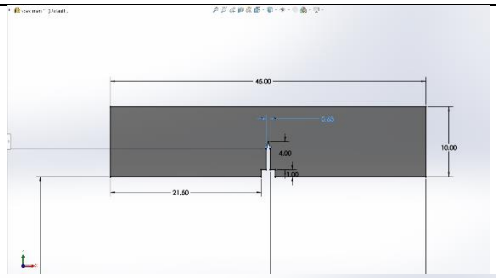
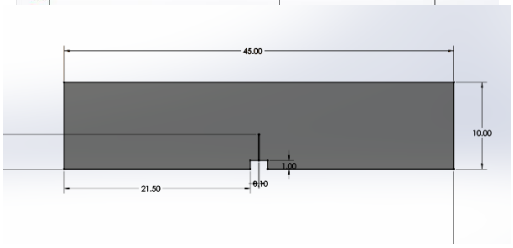
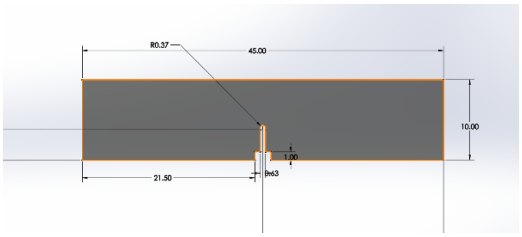
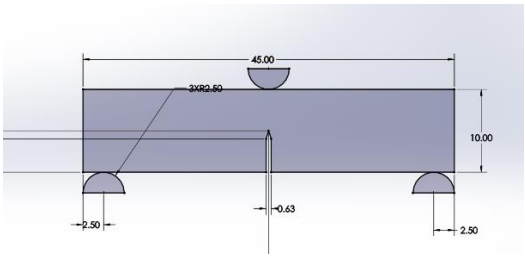
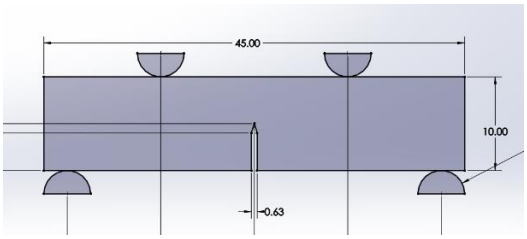
The materials that has been used in the research is AL6061-T6, AL7075 and AL7075-T6. The mechanical properties of the materials are as Table 1.

Table 1: Mechanical properties of Aluminium alloys for simulation.

Mechanical properties	AL6061-T6	AL7075	AL7075-T6
Young's Modulus, E	68.9 GPa	71.7 GPa	70GPa
Poisson ration, v	0.33	0.33	0.33
Ultimate Tensile Strength	262 MPa	572 MPa	560 MPa
Shear Strength	207 MPa	331 MPa	330 MPa

5 specimens are prepared according to ASTM standard for fracture toughness testing. From the ASTM standard, the specimens are as Table 2.

Table 2: Specimen Geometry Based on ASTM Standard

Type of specimen	Dimension
	1. Straight through notch Length = 45 mm Thickness = 5 mm Width = 10 mm Notch diameter = 0.63 mm
	2. Narrow Notch Length = 45 mm Thickness = 5 mm Width = 10 mm Notch diameter = 0.10 mm
	3. Drilled hole ended notch Length = 45 mm Thickness = 5 mm Width = 10 mm Notch diameter = 0.63 mm
	4. Three point bend Length = 45 mm Thickness = 5 mm Width = 10 mm Notch diameter = 0.63 mm
	5. Four point bend Length = 45 mm Thickness = 5 mm Width = 10 mm Notch diameter = 0.63 mm

2.2 Methods

A three point bending and four point bending test was simulated in ANSYS simulation with three different loads which is 2500N, 3750N and 5000N. The specimen geometry was drawn is SolidWorks software according to the dimension in Table 2 and were imported in ANSYS. The materials data, Young's Modulus and Poisson ratio was recorded in the engineering data in ANSYS according to Table 1.

2.2.1 ANSYS Simulation Procedure

After the drawing of the specimen geometry and the engineering data is imported in ANSYS. The specimen geometry will be assigned with each material that has been discussed in the research. After the materials is assigned, the mesh was generated for each specimen and the boundary condition

is applied. The boundary condition for three point bending test is one load and has two fixed support. For four point bending, it has two loads and two fixed support. After the boundary condition has been applied to the three point bending and four point bending test, the solution information will run in order to evaluate the data that was insert in the simulation.

3. Results and Discussion

3.1 Three point bending simulation

Figure 1 shows the lines present for the different specimens geometry. The round dot line referring to the narrow notch specimen and it appears to show the highest stress which is 1308.7 MPa, 1963 MPa, and 2617.3 MPa. The square dash line is represent the three point bend specimen which is the second highest at 652.88 MPa, 979.31 MPa and 1305.8 MPa. The third highest line is present by the straight line is the straight through notch specimen and this specimen has a slight different from the previous mention specimen which is at 651.41 MPa, 977.12 MPa and 1302.8 MPa. The drilled hole ended specimen which is presented by dash dot line recorded the lowest stress at 628 MPa, 942 MPa and 1256 MPa. All data is presented for their respective load applied during the simulation which is 2500N, 3750N and 5000N. In this research, there are 2 other materials that were tested which is AL7075 and AL7075-T6. All specimen geometry exhibit almost the same graph plot as the AL6061-T6. From the comparison of material results, it shows that AL6061-T6 has higher stress than AL7075-T6 and the lowest one is from AL7075 material in all specimen geometry that was used in the research.

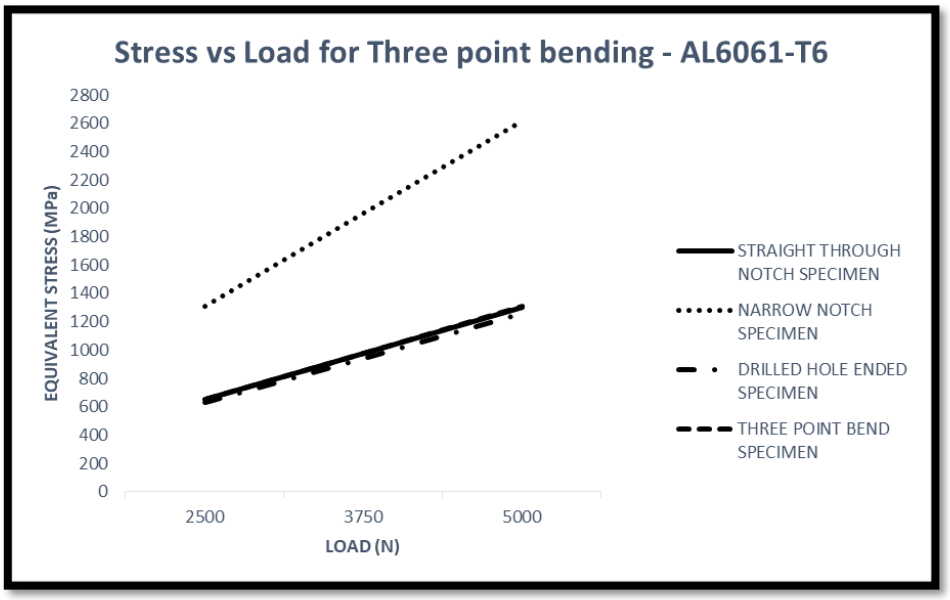


Figure 1: Stress-Load for Material AL6061-T6

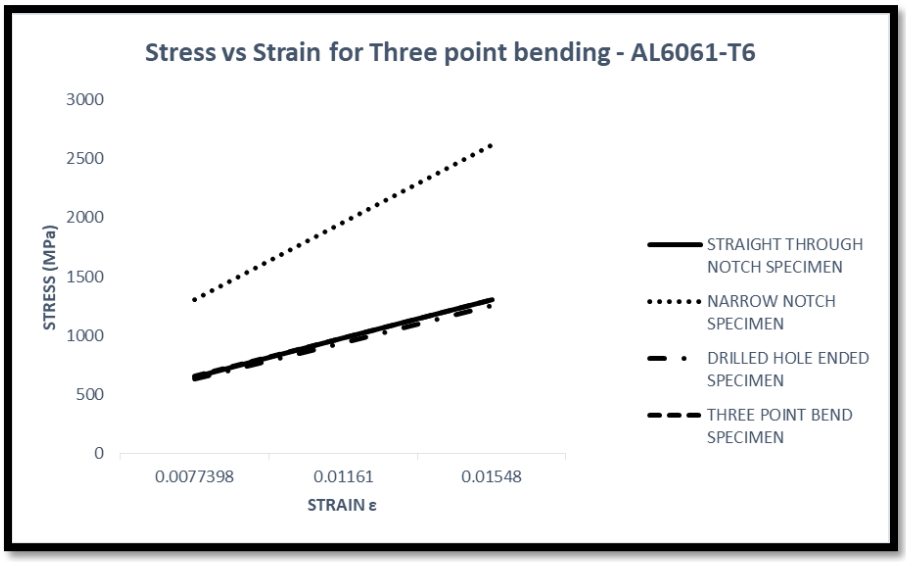


Figure 2: Stress-Strain for Material AL6061-T6

Figure 2 show the lines present for the different specimens geometry for material AL6061-T6. The round dot line referring to the narrow notch specimen and it appears to show the highest strain which is 0.019297, 0.028945, and 0.038594. The square dash line is represent the three point bend specimen which is the second highest at 0.0077638, 0.011646 and 0.015528. The third highest line is present by the straight line is the straight through notch specimen and this specimen has a slight different from the previous mention specimen which is at 0.0077398, 0.01161 and 0.01548. The drilled hole ended specimen which is presented by dash dot line recorded the lowest stress at 0.0083099, 0.012465 and 0.01662. All data is presented for their respective load applied during the simulation which is 2500N, 3750N and 5000N. In this research, there are 2 other materials that were tested which is AL7075 and AL7075-T6. All specimen geometry exhibit almost the same graph plot as the AL6061-T6. From the comparison of material results, it shows that AL6061-T6 has higher strain than AL7075-T6 and the lowest one is from AL7075 material in all specimen geometry that was used in the research.

3.2 Four Point Bending Simulation

Figure 3 shows the lines present for the different specimens geometry. The long dash dot line referring to the four point bend specimen and it appears to show the highest stress which is 869.29 MPa, 1303.9 MPa, and 1738.6 MPa. The straight line is represent the straight through notch specimen is the second highest and this specimen is slightly lower than the four point bend specimen which is at 868.91 MPa, 1303.4 MPa and 1737.8 MPa. The third highest line is present by the dash dot line is the drilled hole ended specimen which is at 858.08 MPa, 1287.1 MPa and 1716.2 MPa. The narrow notch specimen which is presented by round dot line recorded the lowest stress at 848.63 MPa, 1272.9 MPa and 1697.3 MPa. All data is presented for their respective load applied during the simulation which is 2500N, 3750N and 5000N. In this research, there are 2 other materials that were tested which is AL7075 and AL7075-T6. All specimen geometry exhibit almost the same graph plot as the AL6061-T6. From the comparison of material results, it shows that AL6061-T6 has higher stress than AL7075-T6 and the lowest one is from AL7075 material in all specimen geometry that was used in the research.

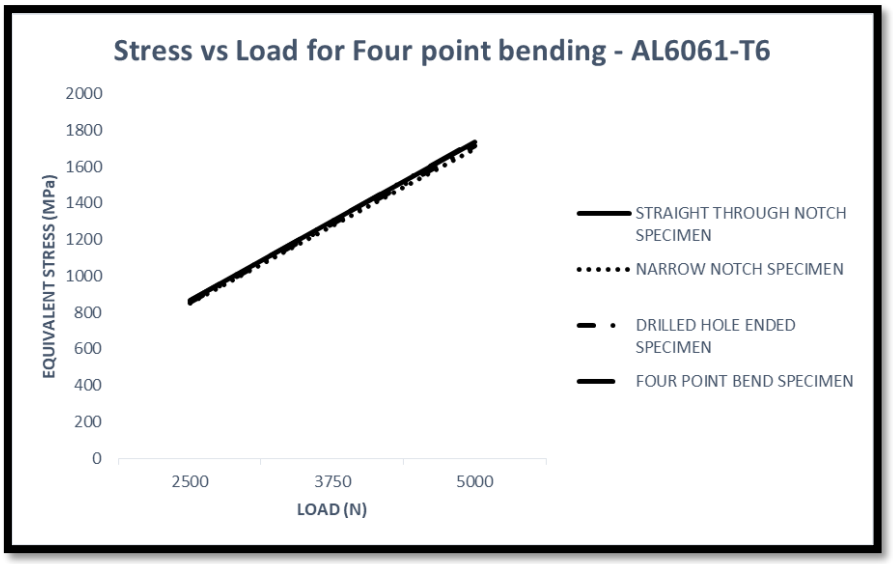


Figure 3: Stress-Load for Material AL6061-T6

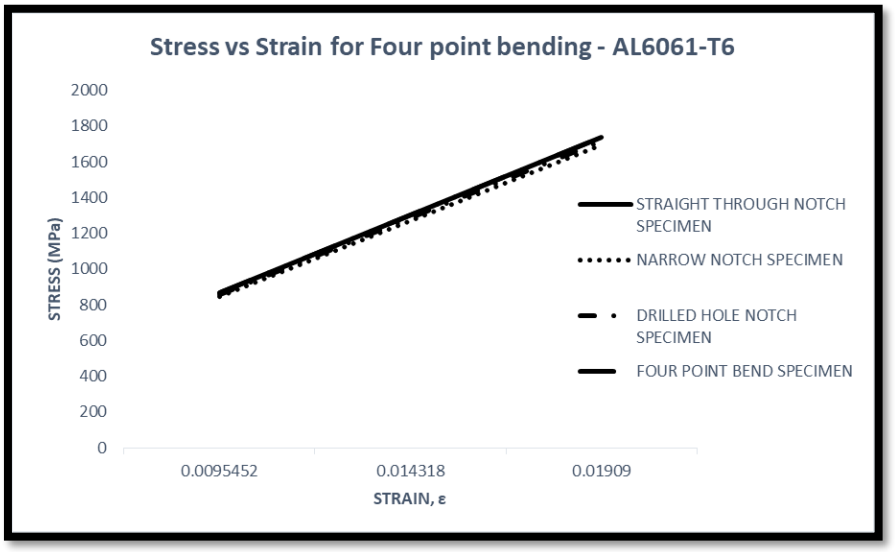


Figure 4: Stress-Strain for Material AL6061-T6

Figure 4 shows the lines present for the different specimens geometry. The long dash dot line referring to the four point bend specimen and it appears to show the highest strain which is 0.0095638, 0.014346, and 0.019128. The straight line is represent the straight through notch specimen is the second highest and this specimen is slightly lower than the four point bend specimen which is at 0.0095452, 0.014318 and 0.01909. The third highest line is present by the dash dot line is the drilled hole ended specimen which is at 0.0093987, 0.014098 and 0.018797. The narrow notch specimen which is presented by round dot line recorded the lowest stress at 0.0092779, 0.013917 and 0.018556. All data is presented for their respective load applied during the simulation which is 2500N, 3750N and 5000N. In this research, there are 2 other materials that were tested which is AL7075 and AL7075-T6. All specimen geometry exhibit almost the same graph plot as the AL6061-T6. From the comparison of material results, it shows that AL6061-T6 has higher stress than AL7075-T6 and the lowest one is from AL7075 material in all specimen geometry that was used in the research.

3.3 Three Point Bending Analysis

Referring to the results obtained from the simulation of three point bending test of the specimens, the stress increase as the load increase. The three point bending is used to measure the behaviour of materials subjected to a single beam loading and as for the results shows that all specimens undergo plastic deformation after the stress value for the specimen exceed the yield strength of the material during the loading condition increase from 2500N to 5000N. This situation occurred because the specimen want to resist the fracture. When the stress increase and further beyond the elastic limit, the specimen undergoes the plastic deformation. From the results, all SENB specimen shows the plastic deformation at notch end. This is because all specimen geometry in this research has different type of notches. According to the previous research that had been conducted to investigate the effect of notches on fracture behaviour in NiTi shape memory alloys[6], it has been discussed that different that the different type of notches and notch sizes can affect the specimen behaviour in a different way.

Furthermore, the narrow notch specimen appears to show the highest stress and strain compared to the other specimen geometry that was discussed in the research. This is because the notch diameter size is the smallest compared to the other three specimen geometry which is at 0.10 mm. The other 3 specimens has almost the same results is because the diameter of the notches is the same which is 0.63 mm and the differences between them is only for the shape of the notch. The smaller notch size specimen need high stress in order to bend the specimen under direct loading roller so that the specimen can deform plastically after the loading condition was applied. From the research conducted by[6], it has been discussed that the maximum stress is appear to be in the specimen with smaller notch size. From the comparison of materials in this research, it has been shown that for three point bending test simulation, AL6061-T6 material has the highest stress and strain compared to the other two materials which is the AL7075 and AL7075-T6. This because the chemical composition for AL6061-T6 material is better which is it has more Silicon and Chromium composition compared to the other two materials which can be observed in Table 3[7] and 4[8] respectively.

Table 3: Chemical composition of AL7075-T6 and AL6061-T6

Element	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Si	Al
AL7075-T6	0.4	1.6	0.1	2.5	5.4	0.021	0.23	0.35	Remaining
AL6061-T6	0.45	0.3	0.11	1	0.09	0.041	0.24	0.6	Remaining

Table 4: Chemical composition of AL7075

Element	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Si	Al
AL7075	0.5	1.6	0.3	2.5	5.5	0.2	0.15	0.4	Remaining

3.4 Four Point Bending Analysis

Referring to results obtain from the simulation of four point bending test of the specimens, the stress increase when the load increase. From the results, all SENB exhibit plastic behaviour. This situation happened because the specimens want to resist fracture. When the stress increased gradually and it beyond the elastic limit, the specimens will undergo plastic deformation. The plastic deformation area is greatly concentrated at the notch end. For the plastic deformation at the notch end for the specimens where the notch specimens experiences an opening and it gets bigger when the load is increase. This is because the higher the amount of plastic strain on notch tip and the bigger the plastic zone size indicate the higher resistance towards the crack initiation in specimen with the highest load applied compared to the lowest load[9]. In four point bending, the maximum flexural stress is spread over the section of the beam between loading points thus, the results shows that the stress data for narrow notch is lower compared to the data from three point bending simulation. This is because of the

location of the maximum bending moment and maximum axial stress. The maximum stress occurs directly below the loading roller for the three point bending and it is spread out over the area between the two loading roller for four point bending[10]. Four point bend specimen has the highest stress and strain compared to other specimen geometry. As we can obtained from the results, the four point bend specimen has the highest stress value because when the maximum stress is spread over the area of the loading roller, the specimen which have the bigger notch diameter as for the four point bend specimen has 0.63 mm diameter will need high stress value to bend the specimen under the four point bending. As for the material, in four point bending, AL6061-T6 also the highest because the mechanical properties. AL6061-T6 is a high ductility material so that it need high stress in order to bend the specimen so that the specimen can undergo plastic deformation.

4. Conclusion

Based on the simulation analysis that has been conducted, the main objective of this research is to determine the mechanical properties of Aluminium alloys using simulation method are achieved. The results is then compared with data from other research. The specimen that has been used in this research is single edge notch bend (SENB) specimen with different configuration. The material that has been used is AL6061-T6, AL7075 and AL7075-T6. There were three different load was applied to the specimen which is 2500N, 3750N and 5000N. Result and data recorded shows that when the load applied is increased, the stress of the specimen increased. This is because the specimen is able to withstand the greater amount of load that was applied. The result that was obtained from the three point bending test simulation shows that the narrow notch specimen has the highest stress and for the material is AL6061-T6 compared to other two materials. The result that was obtained from the four point bending test simulation shows that the four point bend specimen has the highest stress for the material AL6061-T6 when compared to other two specimens. The results shows that the material properties of AL6061-T6 is the best because it has the highest equivalent elastic stress value compared to the other two materials and for the specimen geometry, the narrow notch specimen is the best because of the mechanical properties as it has the highest equivalent stress and equivalent strain. On the other hand, we can conclude that the result shows that all specimen exhibit the same result which is all specimen tend to undergo plastic deformation as the stress value obtained from the simulation is exceed the material's yield strength.

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